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Monterey, California

THE HISTORY, OPERATION AND PERFORMANCE
OF AN EXPERIMENTAL
AUTOMATIC WEATHER STATION IN ANTARCTICA

by

Robert J. Renard and Manuel G. Salinas

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ABSTRACT

The paper describes the prototype Automatic Weather Station platform (AWS), developed at Stanford University, and presents an evaluation of the data produced by its temperature, pressure and wind sensors while the platform was deployed at three locations on Antarctica (South Pole, McMurdo and Marble Point) during the years 1975-77. The major purpose of the Antarctica test was to monitor the durability of the platform and its sensors and electronics, under harsh climate conditions. Instrument redundancy was employed for the measurement of pressure and wind. Data transmission from the sensors was effected by the Nimbus 6 Random Access Measurement System (RAMS). The evaluation is represented by a statistical analysis of the deviations of AWS readings from official observations at South Pole and McMurdo, as appropriate. These indicate that the pressure transducers functioned well throughout the period while temperature and wind sensors malfunctioned at various times. Deviations for most instruments exceeded those of the manufacturer's stated accuracies. The usable data period extended from 26 June 1975 to 20 July 1976. The platform transmitted data via RAMS from 26 June 1975 to 5 May 1977, although the data in the period after 20 July 1976 were considered meteorologically not useful.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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1. Introduction

The Automatic Weather Station (AWS) platform was developed under the guidance of Dr. A. Peterson and Dr. M. Sites, Department of Electrical Engineering, Center for Radar Astronomy, Stanford University, Palo Alto, California with funding provided by the National Science Foundation (NSF). AWS originated as an experimental remote-sensing station which would operate in harsh environments, such as the continent of Antarctica, with minimum maintenance. The station was designed to transmit its sensor data to the polar orbiting Nimbus 6 weather satellite via the Random Acess Measurement System (RAMS).

The initial deployment of the prototype AWS to Antarctica had as its main intent to test the cold-weather durability of the platform, electronics and sensors. The authors, under the sponsorship of the Polar Programs Office, National Science Foundation, undertook the task of documenting the history, operation and performance of the AWS platform. It is to be noted that the AWS platform development and deployment were accomplished prior to the investigators' involvement in the evaluation study.

2. The AWS Platform and its Instrumentation

a. Platform

AWS is a semi-portable station consisting of a 3 m (9.8 ft) triangular tower, assorted environmental sensors, omnidirectional antenna, and power source[1] (Fig. 1). The station

[1] A propane generator was employed as a backup power supply at the South Pole.

is powered by a radioactive thermo-generator. The heat given off by the decay of the isotope Strontium 90 is converted into electrical energy by a solid-state device. The thermo-generator is positioned on the ground atop a sled-like platform at a distance of several yards from the tower. Cables connect the power supply to the electronic circuit boards and various sensors. The unit is capable of providing energy to drive the electronics for approximately five years. The electronic circuit boards, two pressure transducers, heating element, and thermistor are housed in a 2x2x2 ft insulated steel box mounted at about mid-level of the tower. Six inches of insulating material were used to line the interior walls of the box. The simple resistance-type heating element, controlled by a thermostat, maintains an interior temperature approximately 55°F warmer than the ambient, to provide a more tolerable environment for the circuit boards and transducers. Each of the three wind sensors are supported on a horizontal spar fastened to the top of the triangular tower. The ambient air temperature probe is mounted on one of the spars and is encased in a one-inch vertically-oriented tubular shield covered with metallized mylar but non-aspirated. An omnidirectional radio transmitting antenna is positioned atop the center of the tower and is the highest part of the structure. The base of the tower is firmly implanted into the ground or snow, with supporting guy wires to further protect the entire structure from strong winds.

b. Instruments

Specifications and a brief description of the theory of operation for each sensor are presented, as derived from manufacturer brochures (to include instrument accuracy) and Stanford University developers (to include resolution of system). Specification units used in this section were chosen for compatibility with ground-truth station observational units in the evaluation section. Redundancy was employed in pressure and wind sensors to evaluate the performance of instruments with slightly different designs in the severe environmental conditions common to Antarctica.

Temperature:

a. The Platinum Resistance Temperature Sensor Model 101-10-A-3-B-3-2-0 is manufactured by the Weed Instrument Company, Inc., Elgin, Texas. The manufacturer's specifications follow.

Resistance at 32°F:	1000 ohms
Temperature Range:	-320°F to +500°F
Sheath Diameter:	3/16 in
Sheath Length:	5 in
Sheath Material:	type 316 Stainless Steel
Accuracy:	$\pm$ 0.50°F or .25% of temperature being measured, whichever is greater, from -320°F to +500°F

The platinum wire is connected across the feed loop of an operational amplifier. With a known input current feeding the system, as the resistance varies over the platinum wire

(due to temperature change) so does the output voltage of the circuit, according to the equation:

$$V_o = KV_I \frac{R_{wire}}{R_I} \qquad (1)$$

where V_o = output voltage

V_I = input voltage

R_{wire} = resistance of platinum wire

R_I = internal resistance

The sensor has a linear resistance-temperature response over a wide range. In the prototype, the temperature sensor was calibrated for a range of -130^{o}F to +20^{o}F. The signal is time-averaged for somewhat less than 1 sec, with a temperature resolution of $\simeq$ 0.6^{o}F.

b. The Equipment Temperature Thermistor is a conventional thermistor in which the resistance changes quickly with temperature. The response is essentially linear over a small change of temperature; this was considered adequate for monitoring the internal temperature of the insulated box. An approximate calibration curve is used to describe the resistance-temperature response.

Pressure:

a. The Vibrasense Pressure Transducer Model PT-020S-5D is manufactured by Hamilton Standard, a division of United Technologies, Windsor Locks, Conn. The manufacturer's specifications follow.

Range:	0-1379 mb
Repeatability:	± 0.0001% (typical error)
Hysteresis:	0 (typical error)
Long Term Stability (1 yr):	± 0.0827 mb (typical error)
Excitation:	input = +15 vdc; 2.6 a
	output= -15 vdc; 0.04 a
Output:	square wave 4500-5500 Hz, TTL compatible
Temperature Range:	$-29^{o}F$ to $+129^{o}F$
Transducer Size:	5.25 in length x 3.52 in diameter
Weight:	1.8 lb

The Vibrasense transducer converts sensed gas pressure into a square wave electrical signal whose frequency is a function of the sensed pressure. The transducer is composed of two concentric cylinders, separated by an evacuated space which becomes the absolute pressure reference. These cylinders, while separate at one end, share a common mounting base. The walls of the inner cylinder are made to vibrate at their lowest natural frequency by force pulses from the magnetic field of a driver coil mounted internal to the inner cylinder. A pickup coil produces a voltage proportional to the frequency and amplitude of the cylinder wall vibration. The ambient pressure force is exerted on the walls of the vibrating cylinder and increases the cylinder natural frequency according to the non-linear relationship

$$P = A + Bf + Cf^2 + Df^3 + Ef^4 \qquad (2)$$

where

P = pressure

f = natural frequency of vibration

A,B,C,D and E = calibration constants

The natural frequency of the sensor at zero absolute pressure is a finite value dependent upon the pressure range of the transducer. The transducer output signal is a TTL (transitor-transitor logic) compatible square wave, the frequency of which is proportional to pressure. The calibration range employed is 4875.7 to 4997.6 Hz corresponding to 544 to 726 mb, respectively. The output signal is time averaged for 33.6 sec; the resolution is 0.71 mb.

b. The Digiquartz Pressure Transducer Model 215A is manufactured by Paroscientific, Inc., Redmond, Wash. The manufacturer's specifications follow.

Range:	0-1034 mb
Repeatability:	0.005%
Hysteresis:	0.005%
Long Term Stability (6 mo):	0.008%
Nominal Frequency Excursion (zero to full scale):	40 kHz to 36 Hz
Operational Temperature Range:	$-65^{\circ}F$ to $+225^{\circ}F$
Power Requirements:	6v, 0.001a
Size:	0.89 x 1.56 x 1.56 in
Weight:	0.4 lb

The key sensing element in the Digiquartz Transducer is a quartz-crystal oscillating beam whose resonant frequency

varies with pressure induced loads. A fixed-fixed beam vibrating in its first flexural mode is used as the resonant element because it can be made highly sensitive to force inputs while remaining stress free under zero applied load. Quartz crystal was chosen because of its elastic properties, long-term stability, ease of vibrational excitation and low temperature sensitivity. The resonant frequency of the vibrating beam is determined by its dimensions, composition, and stress load. The crystal is fastened to a mechanical structure which can transmit forces to it, that is, the pressure induced load. When the mechanical structure is under tension the frequency increases, when under compression the frequency decreases. The structure has a much lower resonant frequency than that of the vibrating beam and therefore acts as a low-pass mechanical filter. The beam is driven at its resonant frequency by piezoelectric excitation. Four electrodes are vacuum deposited on the beam such that the diagonally opposed electrodes are connected. The beam is forced into flexural vibration by an oscillator circuit which tunes itself to the beam's resonant frequency. The frequency output of the transducer was calibrated in the range 37.8488-38.1333 kHz corresponding to 645.47-719.96 mb, respectively. The signal is time averaged for 15.36 sec and the resolution is given as 0.27 mb.

Wind:

a. The Aerovane Transmitter, modified Model 120, is manufactured by the Environmental Science Division of Bendix Corp., Baltimore, Md. The manufacturer's specifications follow.

Size:	22 in long x 22 in high	
Rotor:	3 bladed, 12 in diameter	
Weight:	13 lb	
Power Requirements:	115 v, 60 Hz, single-phase	
Wind Speed--		
Range:	0 - 174 kt	
Distance Constant:[2]	15 ft	
Output:	14.59 vdc for 120 kt, linear	
Accuracy:	Range	Average Error
	0-8.5 kt	$\pm$ 0.4 kt
	8.6-174 kt	$\pm$ 0.9 kt
Wind Direction--		
Range:	full 360°	
Distance Constant:	34 ft	
Output:	from 5 or 10 ohm potentiometer	
Accuracy:	$\pm$ 2° over the full 360° range	

Wind speed is measured by the three-bladed rotor, which is coupled to a DC magneto, the output voltage of which is directly proportional to wind speed and linear throughout its range. The rotor responds to wind speeds as low as 0.9 kt, while the aerovane provides full tracking at approxi-

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[2]Distance Constant is defines as the length of air (ft) which must pass the transmitter vane to cause it to achieve a 63% response to a sharp change in wind direction.

mately 2.2 kt. Wind direction is obtained by a precision potentiometer mounted to the vane shaft at the base of the sensor. The position of the aerovane over the potentiometer is outputed as an analog voltage, the voltage being directly proportional to the angular deviation of the vane from a reference point on the potentiometer. The voltage is in turn changed into a frequency output for eventual calibration purposes. The wind speed calibration range, signal time averaging constant and resolution were not available to the author. The wind direction calibration frequency range for the instrument is 8966 Hz to 12350 Hz, corresponding to the direction range from 0° to 360°, respectively. The output frequency is time averaged for 0.96 sec; the resultant resolution ≈ 2°.

b. The Model VA-310A Anemometer is manufactured by J-TEC Associates, Inc., Cedar Rapids, Iowa. The manufacturer's specifications listed below apply over the following environmental conditions:

Temperature:	+14°F to 104°F
Relative Humidity:	0 - 100%
Salinity Exposure:	20 - 40 0/00
Power Requirements:	+12v ± 5% at 12 ma

Wind Speed--

Range:	0 - 152 kt
Output:	approximately a square wave with minimum voltage of less than + 1 v, maximum voltage of 10 v ± 1 v

Non-repeatability, Hysteresis and Linearity:	$\pm$ 1% rms

Wind Direction--

Range:	full 360°
Distant Constant:	36 ft at wind velocities of 6 kt or greater
Output:	from potentiometer
Accuracy:	$\pm$ 4° for speeds of 4 - 10 kt $\pm$ 1.9° for speeds greater than 10 kt; additional error < 2° may result from the direction transducer and readout system

Wind speed on this sensor is measured by the vortex sensor head mounted above the vane axis. A small circular rod is exposed to the approaching wind in the sensor head. When the air stream passes by the rod, a series of vortices are formed in the wake of the rod. These vortices are formed in a precise pattern in which the frequency of formation is directly proportional to the approaching wind speed. The equation describing the relationship between the vortex frequency and wind speed is given by

$$f = K \frac{V}{d} \qquad (3)$$

where

K = proportionality constant

f = vortex frequency (Hz)

V = wind speed (m/sec)

d = rod diameter (m)

"K" is commonly called the Strouhal Number after one of its early investigators. The linear relationship between frequency and velocity permits operation of the unit over a wide speed range, and additionally, the linear relationship is maintained irrespective of changes in air temperature and pressure, as seen in equation (3). The vortices generated by the rod modulate an acoustic beam behind the rod, the modulation in turn being detected, processed and produced as a pulse train. The calibration frequency versus wind speed range used is 0 - 8668.78 Hz corresponding to 0 - 95.74 kt. The signal is time averaged for 60.48 sec and the resolution is advertised as 0.374 kt. Direction sensing in the anemometer is similar to Bendix described above. A dual arm potentiometer is used for an analog direction readout. The wind direction calibration range, signal time average and resolution were not available to the author.

c. The Model 011-2B Wind Speed Transmitter was developed by the CLIMET Instruments Company, Redlands, California. The manufacturer's specifications follow

Range:	0 - 87 kt
Threshold:	1.09 kt
Accuracy:	± 2% or 0.22 kt (whichever is greater)
Operation:	magnet-operated hermetically-sealed reed switch
Output Frequency:	63.4 closures/sec at 87 kt
Contact Rating:	0.5 a resistive
Weight:	1.3 lb
Height:	12 in overall

The anemometer is composed of a 3-cup sensor assembly that actuates a sealed magnetic reed switch by means of a magnet attached to the sensor shaft. Output signals are a series of contact closures at a frequency proportional to wind speed. The cups are made of Lexan (a polymeric material) while the shaft is stainless steel. The calibration range used is 0 - 63.4 closures/sec corresponding to 0 - 92.82 kt. The output signal is time averaged for 60.48 sec and the resolution is given as 0.362 kt.

3. Data Transmission via Nimbus 6 RAMS

The AWS electronics assembly controls the sampling, storing and transmission of data received by the sensors and power supply. The sensors and generator voltage are sampled and the data bits stored for a four-minute period, whereupon the cycle is repeated. Although the data are stored internally for a four-minute period per sampling, the data are transmitted to Nimbus 6 RAMS (Random Access Measurement System) (Table 1) (Masterson, 1972 and National Aeronautics and Space Administration, 1975) via the omni-directional antenna every minute as a one-second burst. These pulses of data contain a short burst of carrier wave, lasting from 320 - 360 msec, plus 64 bits of modulated information, at the rate of 100 bits/sec, consisting of bit and frame synchronization, platform identification (ID)[3],

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[3]Platform ID 1637 was assigned to AWS by the National Aeronautics and Space Administration for communication with RAMS.

mode of data group (0-3), and four 8-bit words of sensor and generator data (Fig. 2). It requires four modes of data groups, four data words per mode, to disseminate all the sensed platform data. Therefore, these data are received and stored in the Nimbus 6 satellite as a 4x4 array matrix. In the polar regions, the Nimbus's near-polar orbit allows an effective over-the-horizon time equivalent to 5-15 transmission receptions per pass. Since only four transmissions are required to dispatch all the platform data, all sensor data in a sampling period of four minutes can be obtained on one Nimbus 6 pass.

4. Processing the AWS Data

After initial processing by the Meteorological Data Handling System (MDHS) at the National Aeronautics and Space Administration's Goddard Space Flight Center, Greenbelt, Md. (GSFC), the RAMS-acquired data are distributed to users in either punched card, line printer, or teletype format. Included in this semi-processed data is information related to the platform position and/or velocity computation and sensor data, besides station ID and time of observation.

Sensor data were received from GSFC as octal-based numbers in four sets or modes, consisting of four data words each, as explained in Section III. A Fortran IV computer program, developed at Stanford University with minor modifications by the author, was used for final computer processing of the data at the Naval Postgraduate School. Basically, the sensor data were converted into integer units, then run

through a Lagrangian interpolation scheme to plot measured sensor values against calibration values supplied by the sensor manufacturers or devised by the Stanford group.

5. Deployment History of AWS

The AWS prototype was built and made ready for initial testing by early 1975. Dr. M. Sites of Stanford University escorted the unit to Antarctica, establishing and activating the platform at the South Pole in Feb. 1975 (Fig. 3). Periodic manual checkout was performed until 26 June of that year when Nimbus 6 began acquiring data. AWS functioned continuously at South Pole Station until moved under the direction of Dr. J. Kelley (then Program Associate for Polar Meteorology and Oceanography, Division of Polar Programs, National Science Foundation), to McMurdo Station, on Ross Island, Antarctica, December 1975 (Fig. 4). Operations began at that site on 15 December 1975. The platform was again moved on approximately 15 January 1976, this time to Marble Point, approximately 45 nmi northwest of McMurdo, Antarctica. The platform has remained at this site until the present time, and was functional until 5 May 1977. About 57% of the active days are associated with meteorologically usable data, that is, transmitted data which could be converted to credible ambient values.

6. Evaluation of Data from AWS Platform

Most of the available usable AWS data (Fig. 3) from 26 June 1975 (South Pole) - 20 July 1976 (Marble Point)

were computer processed at the Naval Postgraduate School (NPS). However, for the periods 11 August - 24 November 1975 and 16 May 1976 - 20 July 1976, the data were processed at NPS for multiple-day intervals only.

A statistical analysis was performed on the 1975 South Pole AWS data and official observations taken at the continuously-manned weather station. The latter observations were accepted as ground truth but are not to be regarded as absolute standard measures of accuracy. The procedure involved comparing the processed AWS data, sampled at approximately one hour and forty-eight minute intervals, with those of the South Pole Station, sampled every hour, except for the pressure observations which were recorded every six hours. As the AWS observations were sampled at times not coinciding with those at South Pole Station, the latter were interpolated to fit the former in time. Interpolated values for the official pressure observations were derived using the past six-hour tendency recorded with each observation. Due to the six-hour gap between recorded pressures, only AWS pressure data within one hour of an official South Pole reading were used in order to reduce interpolation errors.

As measures of credibility of the AWS sensor data, the following statistical parameters were computed:

$\bar{D}$ = average algebraic difference between the AWS and official measurements

$\overline{|D|}$ = average absolute difference between the AWS and official measurements

RMS = root mean square difference between the AWS and official measurements

s = standard deviation of the individual absolute AWS/official differences from the mean values

As calibration tests of the sensors were not performed after the initial deployment of the AWS station, the evaluation of the platform data was necessarily limited to only a coarse examination of the actual magnitudes of the differences of the AWS observations from those of the appropriate official observation station, a check on the nature and trend of the time-coincident parameter profiles from AWS and official sources, and identification of any major interruptions in the transmission of usable data.

The statistical figures and graphs showing AWS data deviations from official should be taken only as first-guess indications of AWS instrument deficiencies during harsh climate deployment, due to the following:

(1) the semi-objective official observations used for ground-truth are subject to human, mechanical, and electronic errors;

(2) the difference in locations (horizontal, vertical) between AWS and official sensors;

(3) no calibration checks for possible drift of AWS instrument outputs were made after the platform was initially deployed;

(4) the eight bit data-words used to define instrument readings in telemetry places limits on the resolution of the AWS measurements;

(5) the Lagrangian interpolation scheme, used to relate calibration and sensor output values in the processing of transmitted data, is not exact;

(6) the assumption of linearity (for interpolation purposes) between South Pole hourly temperature and wind observations and the subjective use of three- or six-hourly pressure tendencies introduces a source of error, especially for the latter.

The data analyzed were divided into three main groups, based on the location of the AWS platform:

(1) South Pole -

A statistical analysis of AWS observed data was performed using South Pole Station observations as ground-truth. The platform was situated within 50 ft of the South Pole sensors, although the wind instruments on the platform tower reportedly were mounted about 20 ft lower than those of the South Pole Station.

(2) McMurdo -

A rough examination of the sensor readings versus the McMurdo official observations was conducted to determine the functional status of the AWS. The platform was located approximately one quarter of a mile from the base of Observation Hill at an elevation of approximately 280 ft and over 1600 ft distant from the McMurdo weather instruments which are near mean sea level. McMurdo's weather instruments include: an aneroid barometer (ML-401/UM) used for pressure

observation); a marine barograph (used to observe pressure tendency); a Speedomax H temperature recorder with platinum probe; a UMQ-5C wind anemometer/vane; and a wind recorder (RD-108B).

(3) Marble Point -

A gross comparison of the AWS data against McMurdo observations (some 45 nmi to the southeast) was performed to ascertain the status of the sensors and AWS in general. The platform was situated on glacial till beyond Wilson Piedmont Glacier at the mouth of Wright (dry) Valley (Fig. 4).

7. Results

A. Temperature (Fig. 5)

1. 26 Jun - 10 Oct 1975 (South Pole)

The RMS difference between the Platinum Resistance Temperature Sensor values and those at South Pole Station for this period was 2.4°F, with most of this difference arising from the AWS temperatures exceeding the official readings, as evident upon comparing $\bar{D}$ and $\overline{|D|}$. This type of difference could not have resulted from direct insolational heating of the sensor housing, as most observations sampled occurred during the sunless austral winter. The consistency of the positive difference, as exemplified in Figs. 5a and 5b, especially in comparison with the expected accuracy, is highly suggestive of a calibration problem. A lag of the temperature profile features in the AWS observations as compared to South Pole Station, typically 1.5 - 3.0 hours, is also apparent. Despite the apparent lag, the AWS observational trend shows extremely close correlation with the official, although with slightly less detail, at least in part due to the lesser frequency of AWS observations.

2. 15 Oct - 04 Dec 1975 (South Pole)

Sensor values became erratic during this period, with continually decreasing correlation to South Pole measurements (Figs. 5c and 5d). The RMS difference has increased significantly to +8.0°F, and algebraic and absolute

differences nearly quadrupled the values in the previous period. The standard deviation of the errors also increased significantly indicating a much greater spread in the individual differences.

3. 15 Dec 1975 - 20 Jul 1976 (McMurdo and Marble Point)

The AWS readings became fixed at -20.7°F, with minor fluctuations, until failure of the electronics to transmit usable data at the end of the period. It is suggestive that relocation of the automatic station from the South Pole to McMurdo resulted in damage to the sensor and subsequent unusable readings.

B. Pressure (Fig. 6)

1. 26 June - 04 Dec 1975 (South Pole)

Both the Hamilton Vibrasense and Paroscientific Digiquartz pressure sensors performed consistently well throughout the period, matching the South Pole Station measurements closely (Fig. 6a). However, a slight lag in the AWS observations was evident at those times when the official pressure trace changed rapidly. The data during this period were sub-divided into five smaller periods to establish whether any trends in the statistics might be observed. The statistics for these sub-periods are included in the table with Fig. 6.

It is interesting to note the decrease in both Hamilton's and Paroscientific's RMS difference with time, as the austral winter gives way to summer, suggestive of temperature dependent pressure readings. This dependency

may be a result of the sensors operating in temperatures colder than design specifications, even considering the heated insulated compartment in which the transducers are contained. During this period, the South Pole experienced temperatures below -90°F, at times even reaching -100°F. Also, a Lagrangian interpolation scheme was used to match manufacturer temperature correction curves to the measured pressures and this computerized procedure might have introduced a minor portion of the error.

The Paroscientific pressure sensor values showed a larger deviation from official values as compared to the Hamilton, with most values less than official. These differences are believed to be a result of inappropriate Paroscientific calibration values for the pressure ranges encountered at South Pole.[4]

2. <u>15 Dec - 24 Dec 1975 (McMurdo)</u>

Calibration values for both instruments were originally derived for a pressure range of approximately 600-750 mb. During this period the platform was located at McMurdo near mean sea level, where typically pressures range from 970 - 1020 mb. An attempt was made during the data processing to extend the calibration values to pressures near 1000 mb, but this procedure was not entirely successful. Therefore, the instrument could be evaluated only for trend characteristics. As seen in Fig. 6b, both sensors followed

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[4] Originally, it was planned to place the platform over the eastern Antarctica Plateau, which is still higher than the elevation at South Pole. Both instruments were originally calibrated for the former area and Hamilton was recalibrated for the latter area.

the McMurdo observational trace very closely during this ten-day period.

3. 15 Jan - 20 Jul 1976 (Marble Point)

Data from both sensors were compared to McMurdo values, 45 nmi to the southeast. Both sensors mirrored the McMurdo trace well, although the readings were each in a completely different pressure range because of the inappropriate calibration values (Figs. 6c and 6d). The sensors operated until the end of this 1976 period, whereupon the readings became inconsistent and unintelligible, similar to the other sensors (See Table II and Section VIII).

C. Wind Speed[5] (Fig. 7)

1. 26 Jun - 04 Dec 1975 (South Pole)

When operating, both Bendix and CLIMET wind sensors had predominantly lower readings than South Pole Station, which may be mostly due to the AWS sensors being about 20 ft lower than the South Pole anemometer (Fig. 7b). However, both AWS instruments did appear to relate well to the official wind speed trend, although their range was less. Each of the two sensors alternately malfunctioned for varying periods of time in this and subsequent periods. For example, the CLIMET values were transmitted as 0.0 kt for about 30 days beginning 26 June 1975, but performed acceptably well after that. The Bendix instrument meanwhile performed well

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[5] The JTEC wind-speed sensor was inoperable throughout the AWS trial period. It may have been damaged in transit to the South Pole.

early in the period, but began to malfunction around 02 December 1975 (Fig. 7c). Average and RMS differences are well above the error figures supplied by the manufacturers.

2. 15 Dec - 24 Dec 1975 (McMurdo)

The telemetered CLIMET values became fixed at 0.0 kt throughout the period, while the Bendix instrument operation was seemingly normal (Fig. 7d). The relocation to McMurdo could have adversely affected the CLIMET sensor, perhaps jamming the cup assembly. Considering that the platform was over 1600 ft away from McMurdo's instruments and almost 300 ft higher, the Bendix wind speeds still seemed to correlate acceptably with the official observations.

3. 15 Jan - 20 Jul 1976 (Marble Point)

At Marble Point the CLIMET sensor operated well and seemed to reflect McMurdo's trend favorably. The Bendix instrument appeared to perform satisfactorily until an apparent malfunction of the instrument in late February, when data output became fixed at values less than 2.0 kt (Figs. 7e and 7f). This anomaly continued until the end of the period when usable data ceased to be transmitted.

D. Wind Direction[6] (Fig. 8)

1. 26 Jun - 04 Dec 1975 (South Pole)

The period has been divided into sub-periods with associated statistics appearing in the insert table of Fig. 8.

[6] All wind directions are referenced to grid north (Fig. 4).

It is evident that the JTEC sensor's RMS difference increases gradually with time, reaching a high of 35.8°. Examination of the Bendix sensor reveals a rather sudden increase in RMS difference from approximately 15° in the first two sub-periods (26 June-24 July 1975) analyzed to a high of approximately 50° in the last two sub-periods (11 Aug-04 Dec 1975). An explanation for this behavior in the JTEC and Bendix instruments is not readily apparent. Further, there is a bias toward Bendix and JTEC directions being clockwise of official, the bias becoming more predominant with increasing time. For both sensors the RMS and mean differences exceed considerably the manufacturer's error specifications.

After close scrutiny of each sensor's performance, it was noted that the degree of difference from South Pole Station observations appears to be a function of the wind direction and, to a lesser extent, speed of the wind, specifically:

a. 26 June - 05 Sep 1975

(1) South Pole winds between 070°-140° resulted in RMS differences of approximately 15° for both sensors, while the wind speed averaged 8 kt.

(2) South Pole winds between 260°-069° resulted in RMS differences of approximately 18° for Bendix and 38° for the JTEC sensor, while the wind speed averaged 14 kt.

b. 20 Sep - 04 Dec 1975

(1) South Pole winds between 070°-140° resulted in RMS differences of approximately 13° for JTEC (no major change from previous period), while Bendix's RMS difference increased dramatically to 57°. The wind speed averaged 7 kt.

(2) South Pole winds between 260°-070° resulted in RMS differences of approximately 37° for JTEC (again, no major change from previous period), with approximately a 53° RMS difference for Bendix. The wind speed averaged 12 kt.

A mechanical malfunction in the Bendix sensor or its supporting electronics, believed to have occurred around 10 September 1975, may be the cause of the degradation in that sensor's performance during the second (20 Sep - 04 Dec 1975) period. The reason for JTEC's dependency on wind direction and indirectly on wind speed is not understood at this time. Snow drifts are known to have reached at least half-way up the tower supporting the wind sensors at times during the 26 Jun - 4 Dec 1975 period, possibly affecting the local wind field sensed by the instruments.[7]

2. <u>15 Dec - 24 Dec 1975 (McMurdo)</u>

The JTEC sensor was removed from the AWS platform after relocation to McMurdo. The Bendix readings appear

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[7] Personal communication from M. Sites, Ford Aerospace and Communication Corp., Palo Alto, California.

to correlate remarkably well with the official trend (Figs. 8b and 8c), considering that the automatic station was about 280 ft higher than the McMurdo observation station and over one-quarter mile away. No malfunctions were observed.

3. 15 Jan - 20 Jul 1976 (Marble Point)

Correlations with McMurdo observations are inappropriate as the AWS wind directions at Marble Point were probably highly influenced by local topographic effects (Fig. 8d). Again, no apparent malfunctions were evident from the processed data until the major electronics interruption on or about 20 July 1976.

8. Discussion of Results

The evaluation of the various sensors demonstrated, at least in part, the reaction of these instruments to the severe weather regime of Antarctica. However, the apparent errors of the instrument readings appeared to be not only a function of the environmental habitat experienced by the remote station but also a function of improper sensor calibration. It is likely that the instrument calibration settings drifted after initial deployment, but this is not completely resolvable in the coarse statistical analysis performed on the data.

Durability of instruments and electronics is considered essential for the success of remote stations. The pressure sensors evaluated performed impressively throughout the trial period, with no apparent breakdowns. The wind instruments appeared to be the most sensitive to both weather

conditions and relocations of the platform, especially the CLIMET sensor in the case of the latter, as demonstrated by that sensor's moves. The Bendix sensor's data suggested either lubrication or icing problems, although the icing condition if present, was not mirrored in the CLIMET sensor output at those times. Occurrences of Bendix instrument malfunctions were checked against McMurdo observations of temperature and past and present weather. These studies suggested icing was not a problem as temperatures were well below freezing (below 10°F) during these periods, with one exception. During 24 January 1976, temperatures ranged from +14°F to +20°F, with light snow reported, conditions in which icing cannot be entirely ruled out. It is of interest to note that the wind vanes (direction sensing) never demonstrated these particular problems. The disturbance of the natural flow of air by the platform and its instruments represents an unknown factor in the differences of wind speed/direction readings among the various instruments. The temperature probe's readings became erratic after approximately four months of operation at the South Pole; the sensor failed completely after relocation to McMurdo. It is uncertain whether the erratic behavior originated with a problem in the sensor itself or the electronics supporting it. The ultimate failure of the unit probably can be attributed to damage sustained in transit from South Pole to McMurdo.

The complete failure of AWS around 20 July 1976 is thought to have arisen from a malfunction in the electronics circuitry. As evident in Table II, the data received after the breakdown

became erratic in time and unrealistic in content as compared with those data prior to failure. It is highly improbable that all the sensors individually failed at exactly the same time. Either one or more vital electronics component malfunctioned or a voltage fluctuation may have occurred as a result of power supply degradation. Transmissions from AWS eventually ceased on 5 May 1977, almost a full year after initial malfunction.[8] The cause of the total cessation of transmissions is unknown. Notification to Goddard Space Flight Center to discontinue distribution of data from platform 1637 was given on 24 August 1977.

It should be noted that unrealistic output readings were observed occasionally (occurring at random), and are hypothesized to have resulted from atmospheric conditions introducing noise into the transmitted data. This random noise was easily detected in the data and should present no major problems in isolating and removing it in research or operational work.

9. Further Remarks and Recommendations

The development and deployment of more automatic weather stations on the continent of Antarctica, utilizing the expertise gained from the prototype AWS operation, is considered likely in one to two years. These future remote stations, in addition to satisfying the needs of harsh-climate

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[8] In July 1977 three transmissions were apparently received from AWS by Nimbus 6, but this is considered an incomplete observation.

researchers, could serve in upgrading the sparse observational data network of the Antarctica. Enhancing data coverage on the continent is important for several reasons, as follows (Renard, 1975):

(1) The improvement of real-time weather forecasting capability on the synoptic and sub-synoptic scales will be required in support of National Science Foundation sponsored scientific research missions as these enterprises become more lengthy in time and remote in space from established support bases on the continent. The adequate specification of the initial state is necessary to credible forecasting.

(2) Diagnosis and prognosis by numerical means on a global, hemispheric and regional basis depend for success on adequate data input.

(3) Data are necessary for modeling of all scales of weather systems peculiar to the ice/snow covered continent; for example katabatic winds, regional moisture and cloud systems, and ice fog.

(4) Data are required as an indirect source of information to establish ground-truth values for weather satellite observations.

To satisfy these anticipated objectives, it is suggested that future remote observing platforms might employ sensors mounted at several levels, and maintain redundancy as reliability insurance. Instrument readings possibly could be characterized by data-words composed of more than 8-bits to achieve the resoltuion and overall accuracy required for

mesoscale research. A micro-processor might control the sampling activities of the sensors via a Programmable Read-Only Memory (PROM) chip or possibly an Erasable PROM (EPROM), to have the flexibility of changing sensing instructions as required by the particular experiment. The micro-processor chip would make the design versatile and readily adaptable to user needs. Design considerations might be directed toward allowing telemetering of data to a base station for real-time use, besides the research endeavors. This would have the effect of compensation for the loss of data in the event the satellite receiving station becomes inoperative, and, in any case, would allow for data documentation at intervals consistent with mesoscale circulation research (e.g., one hour or less).

Several unique problems arise with the operation of unmanned platforms, such as AWS, in the Arctic or Antarctica:

(1) Maintenance of equipment: during the dark, sunless austral winter of either hemisphere, the weather conditions become hostile enough to preclude the possibility of performing any required maintenance on remote stations.

(2) Power source: if the station is tasked to gather data year-round for subsequent research or climatology, the power supply must have long-life capability (at least six to seven months), since recharging or replacement of a power source would be impossible in the winter.

(3) Communications: remote weather platforms necessarily transmit their data using radio telemetry, as connecting

cables to remote sites would be unrealistic. The polar regions, however, are affected by frequent magnetic storms in the upper atmosphere which can seriously hamper radio transmissions in certain frequency bands.

The maintenance problem cannot be eliminated but can be reduced somewhat through the use of tested, sturdy equipment and weather sensors designed to operate with only minimum maintenance requirements. Additionally, a thorough on-going preventive maintenance program during the summer would have to be considered essential for the continued successful operation of the platform during the winter months. A power source utilizing storage batteries for energy suffers from the cold temperature common in the polar regions, although the latest generation of lithium batteries are rated as having a 5- to 6-month lifetime at temperatures as low as -65°F. Radioactive thermo-generators offer a highly suitable energy source (lifetime ≃ 5 years) although an extremely expensive one. Solar cells would be totally useless during the winter months, with only marginal efficiency in the summer due to low sun angles. Wind-powered generators (Jenny, et al., 1969) might conceivably provide electricity in windy areas of the continent. Communication interference can probably be overcome by the propitious use of frequency bands having the least sensitivity to atmospherics.

10. Other Automatic Weather Systems

A number of types of remote unmanned stations have been used in the Arctic area with varying degrees of success and

may have potential use in the Antarctic. The Arctic Ice Dynamics Joint Experiment (AIDJEX) designed to investigate the interaction of sea ice with the environment has tested various buoy configurations, some of which utilize the RAMS system for communications (Martin and Gillespie, 1976 and Martin, et al., 1977). The buoys evaluated were principally designed for use in determining the movement of ice on the Arctic Ocean as a function of wind. Air-dropable buoys (ADRAMS) were also included in the tests and performed exceedingly well. It should be noted that wind sensors were not incorporated in the buoys evaluated; however, pressure transducers and more recently temperature probes have been utilized.

The Polar Automatic Weather Station (PAWS), developed by the Naval Research Laboratory, has been tested extensively in Alaska with some success (von Wald, 1976). However, the present design of PAWS incorporates mechanical relay switches and vacuum tubes in its circuitry, making it highly vulnerable to damage. Perhaps the use of state-of-the-art electronic components would remedy this potential problem. An unsuccessful attempt was made to extend the PAWS testing at a location near McMurdo, Antarctica during the austral summer 1977.

Evaluation of remote stations on Antarctica has been somewhat limited as compared to the Arctic, but is lately becoming more extensive. Stearns and Schwerdtfeger (1977) of the University of Wisconsin recently evaluated the records of a

remote weather station located 900 m above mean sea level in the Dufek area of Antarctica (82°52'S, 53°12'W). The station was powered by batteries, which are believed to have failed after approximately three and one-half months (18 Jan - 7 May 74) due to the cold temperatures of the area, although the rated lifetime of the batteries is 13 months. The data recorded by the station were inked on recording paper in analog form inside the unit, with no telemetry or real-time transmitting capability. The remote station data were found to correlate reasonably well with observations from "South Ice", a station maintained by the British Transantarctic Expedition, slightly over 100 km away.

Another system presently under evaluation in the United States, which may have potential for work in cold regions, is the Portable Automatic Mesonet (PAM) developed by the National Center for Atmospheric Research (Brock and Govind, 1977). PAM incorporates remote stations that are capable of sampling the atmosphere every minute, if desirable, storing the data at a base station on magnetic tape. A real-time graphics display capability is incorporated into its computerized system, for equipment monitoring and real-time analysis work. Provisions are being made to incorporate as many as 40 of the remote sites into the system at one time. However, PAM has not been tested in a harsh, winter regime as yet.

11. Final Comments

Considering the capabilities, advantages and disadvantages of the AWS platform and other assorted remote observing

systems, one can conclude that although AWS may not be the final answer in sensing atmospheric parameters in the Antarctic by remote stations, no one system will be all things to every researcher or operational meteorologist. Used as one amongst a network of various types and designs of remote platforms and their sensors, AWS has the potential for making a valuable contribution to the further exploration and understanding of weather events in the Antarctic, which can ultimately result in the improved prediction capability of weather events in other regions of the world as well.

TABLE I. System parameters for Nimbus 6 RAMS.

Satellite	Nimbus 6 launched 12 June 75
Orbit	sun synchronous (polar orbit)
Altitude	1100 km
Inclination	100°
Period	108 min
Platform location	± 5 km rms
Data retrieval	32 data bits per transmission plus 32 bits for synchronization, mode, and identification.
Orbits per day	13.5
Capacity of spacecraft including blind orbit storage	1000 platforms
Number of platforms in view at any one time	200 in a circle whose diameter is 6000 km (i.e., antenna pattern covers 55° to 60° latitude at equator)

YEAR	DAY	TIME	TEMP	PAROS	HAMIL	BENDIX (DIR&SP)	CLIMET (SP)	EQUIP. TEMP.
1976	Julian	GMT	°F	mb	mb	grid deg/kt	kt	°F
	16	0015	-20.7	665.5	997.6	107/4.3	4.5	+20.5
	16	0202	-20.7	665.8	997.4	107/5.5	5.6	+22.0
	16	0349	-20.7	665.7	997.1	129/5.9	6.0	+24.8
	16	0536	-20.7	665.8	996.7	161/4.2	4.5	+28.3
	16	0724	-20.7	665.8	997.3	197/4.2	3.4	+29.7
	16	0911	-20.7	665.5	996.7	221/6.3	7.1	+28.3
	16	1059	-20.7	664.9	996.4	226/6.3	6.3	+24.8
	16	1246	-20.7	664.6	996.4	207/6.3	6.0	+24.8
	16	1434	-20.7	663.5	995.8	299/5.5	5.3	+23.4
	16	1621	-20.7	662.7	995.2	304/7.1	7.1	+22.0
	16	1808	-20.7	662.4	994.7	109/1.3	3.4	+20.5
	16	1955	-20.7	661.9	993.8	95/3.4	3.1	+22.0
	16	2143	-20.7	662.0	993.6	109/3.8	4.5	+23.4
	16	2330	-20.7	661.6	993.4	134/5.1	2.7	+25.5
	241	0626	-110.9	676.1	0.0	287/2.2	2.0	+15.5
	241	0811	0.0	0.0	0.0	/0.0	0.0	+244.9
	241	0952	-117.6	713.5	1032.0	19/43.2	2.7	- 7.0
	241	1329	0.0	0.0	966.3	95/7.4	0.0	- 7.0
	241	1522	-117.6	699.3	0.0	38/5.9	4.5	+64.1
	241	2047	0.0	0.0	953.5	2/-4.3	0.0	+14.8

TABLE II. Example of AWS sensor values before (16 January 1976 = Julian day 16) and after (28 August 1976 = Julian day 241) sensor readings became completely erratic on 20 July 1976 (Julian day 202). JTEC wind speed not shown since sensor removed at McMurdo in early December 1975.

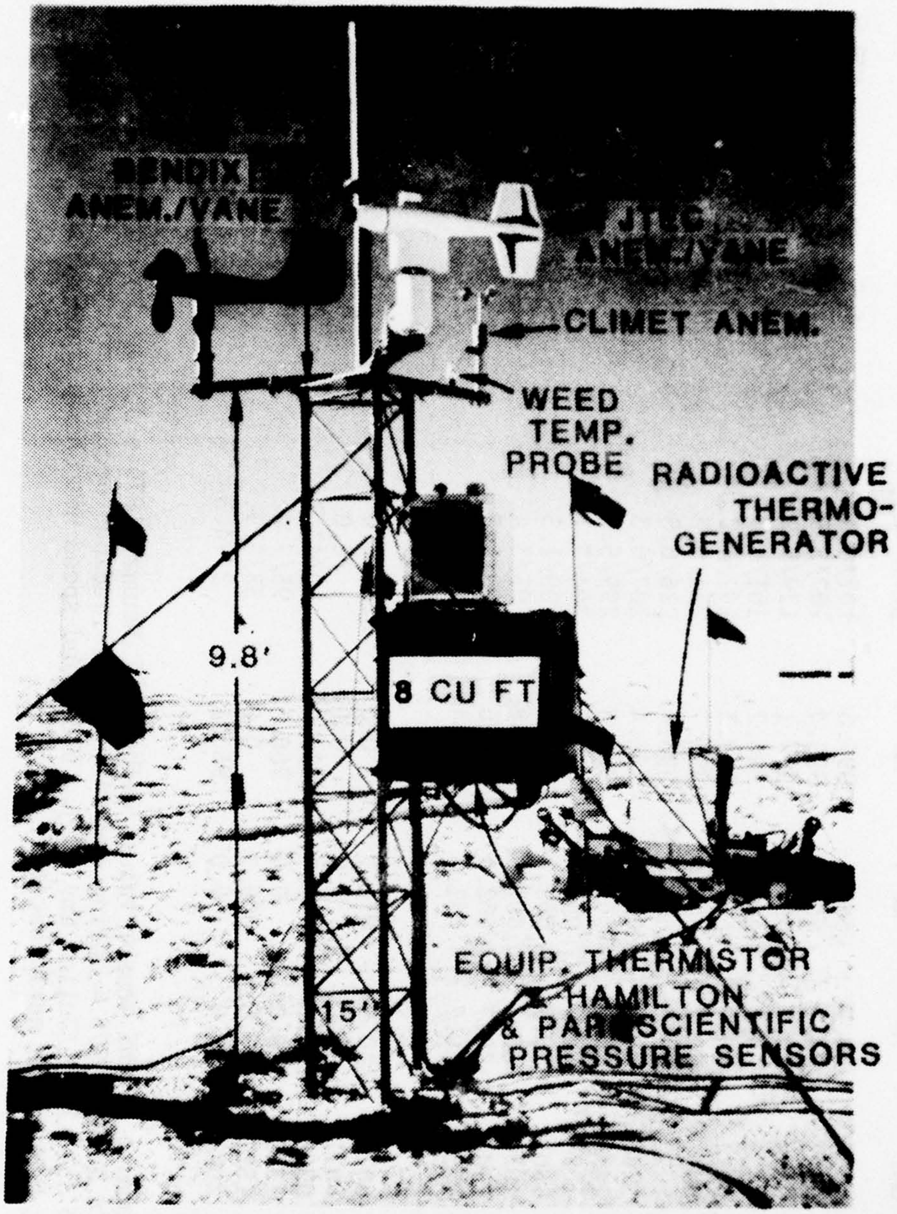


Figure 1. AWS Platform.

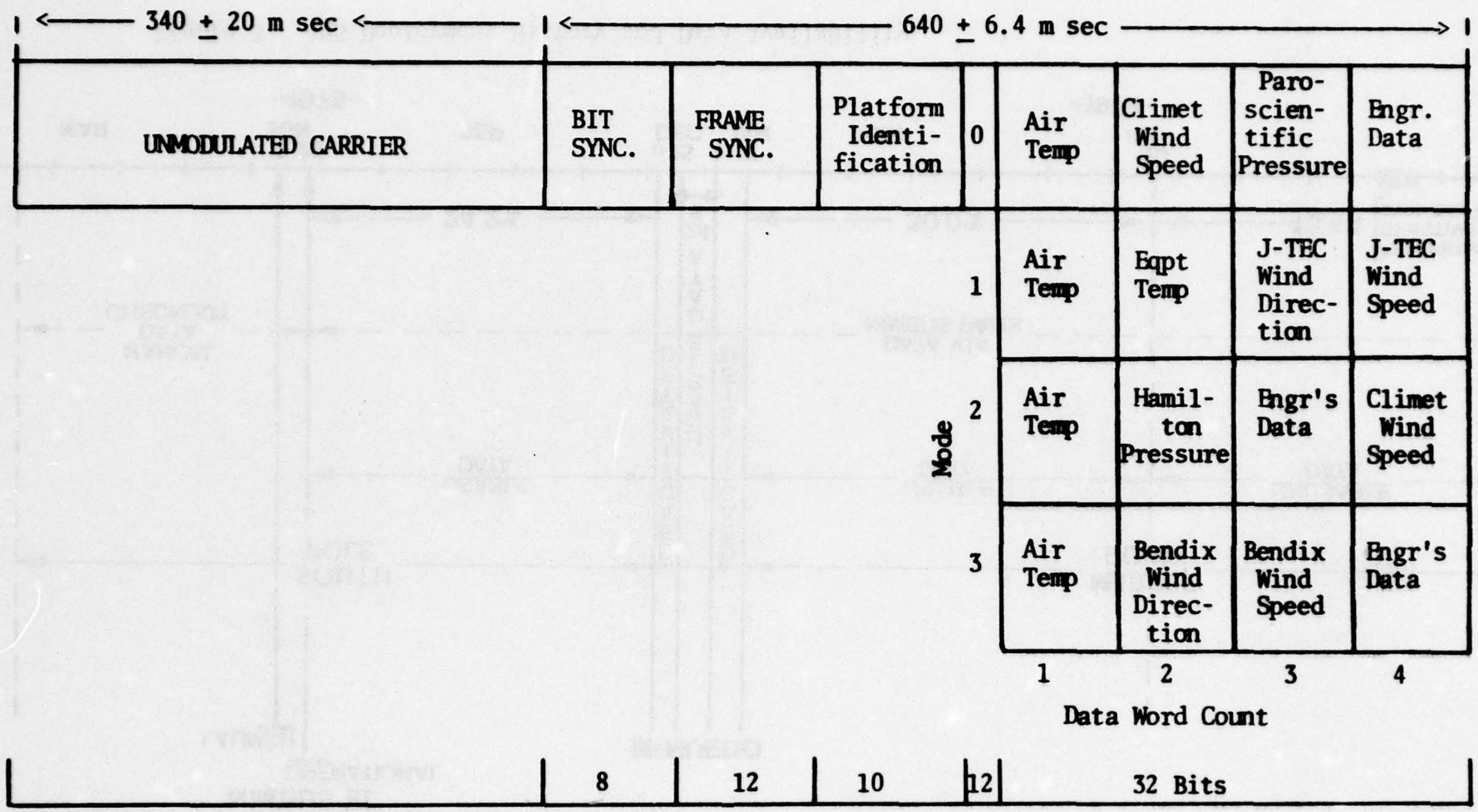


Fig. 2. Format of Transmission from AWS Platform to Nimbus 6 RAMS.

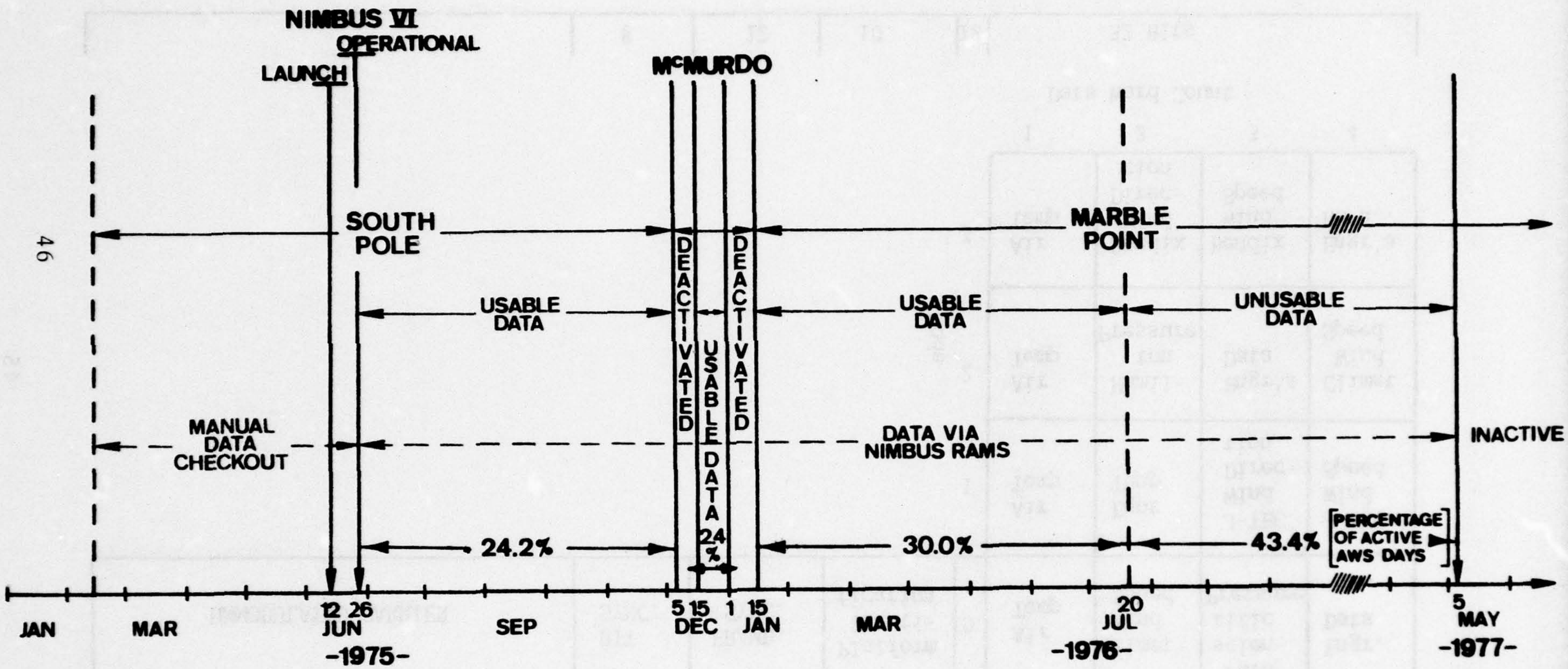


Figure 3. AWS Deployment History and Data Availability.

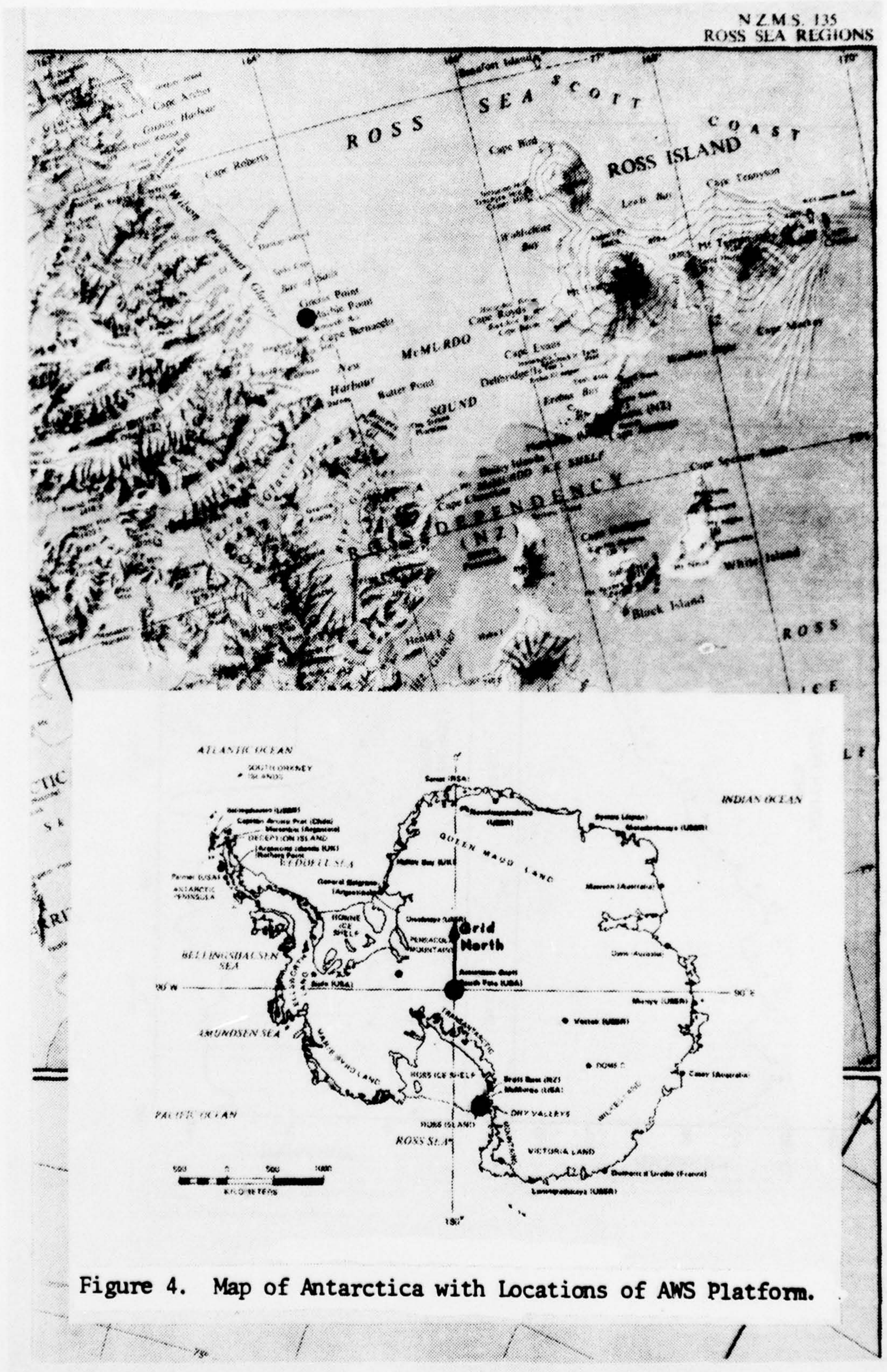
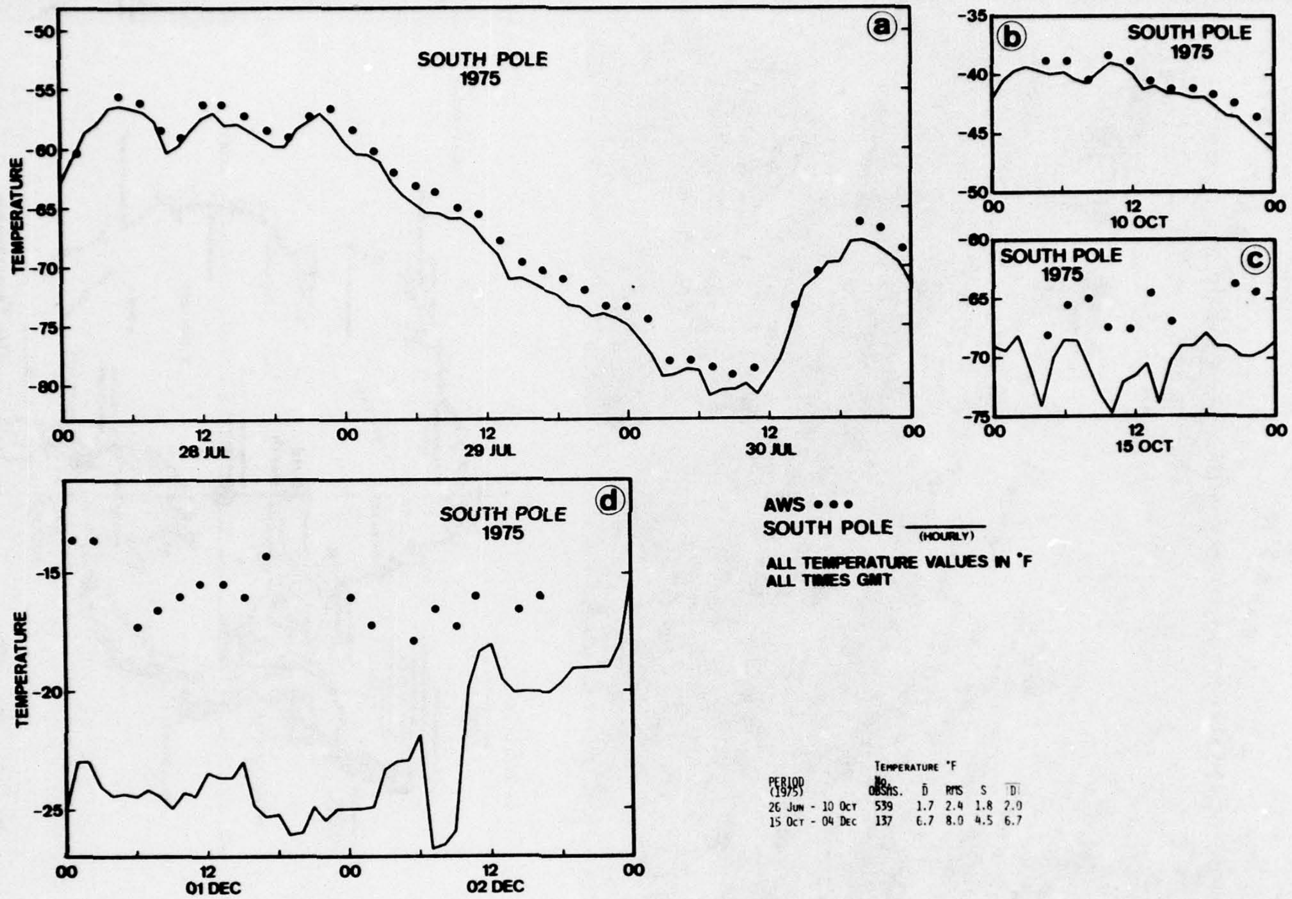
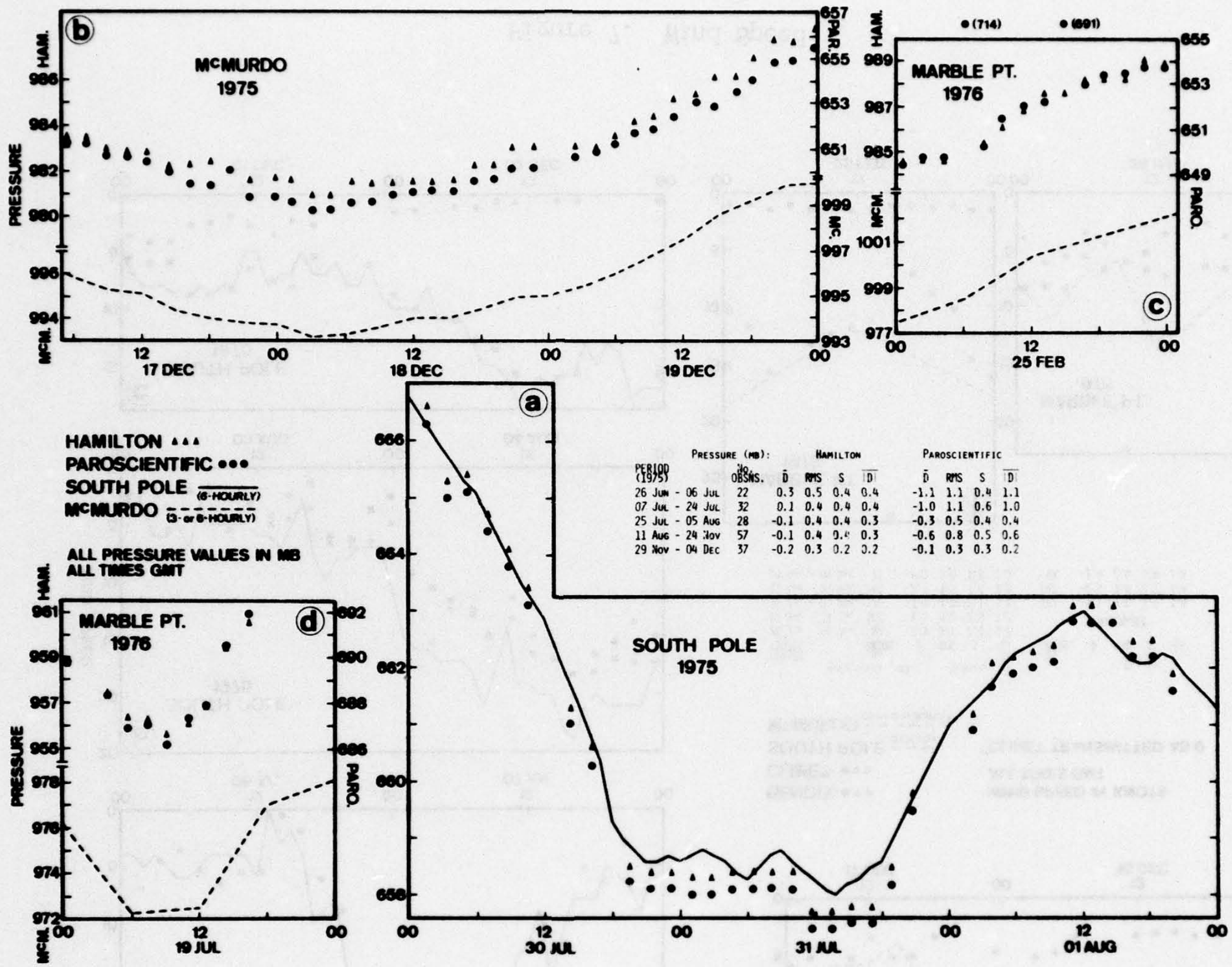


Figure 4. Map of Antarctica with Locations of AWS Platform.



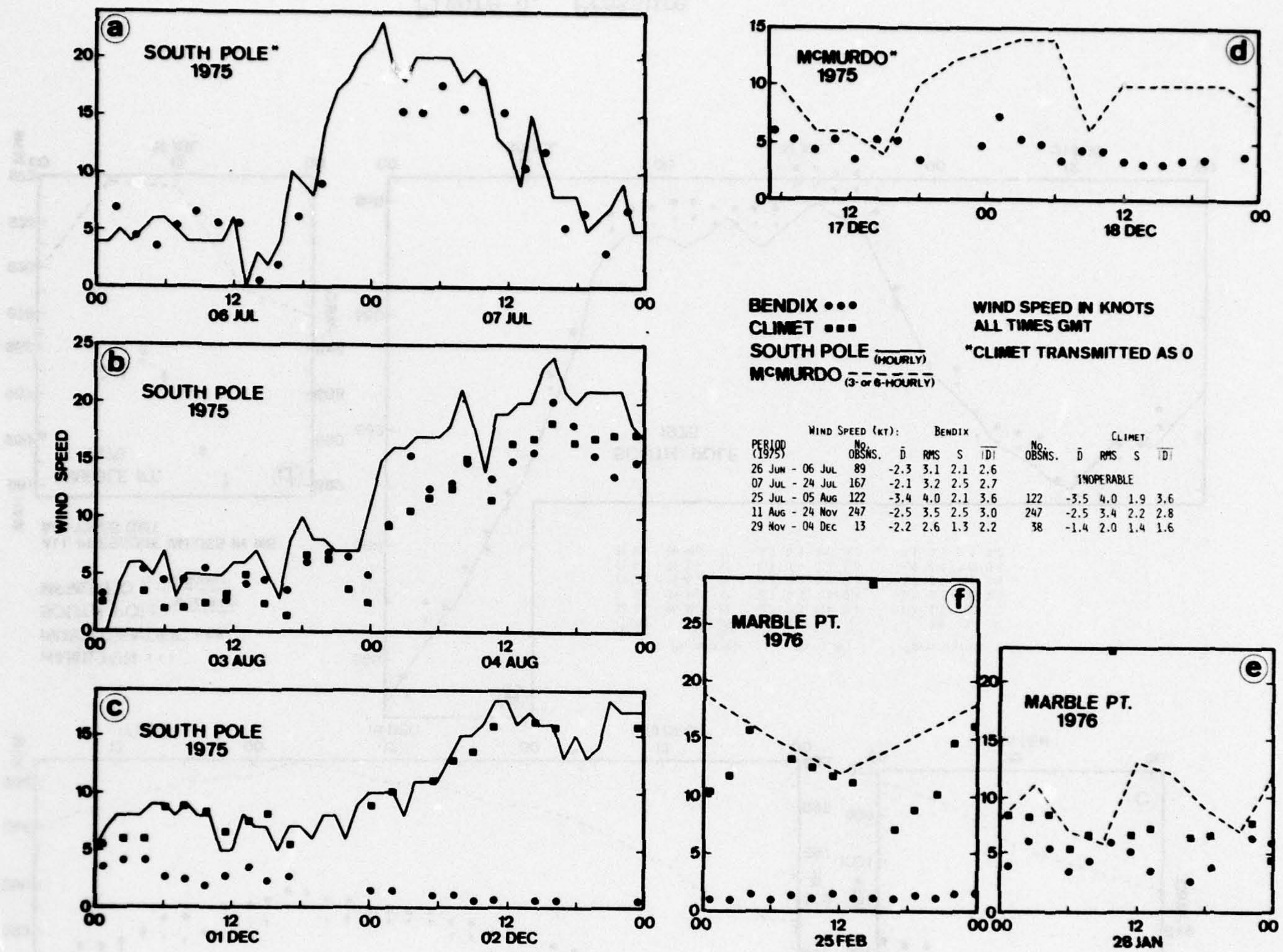
PERIOD (1975)	Temperature °F No. OBSNS.	$\bar{D}$	RMS	S	$\overline{\lvert D \rvert}$
26 Jun - 10 Oct	539	1.7	2.4	1.8	2.0
15 Oct - 04 Dec	137	6.7	8.0	4.5	6.7

Figure 5. Temperature



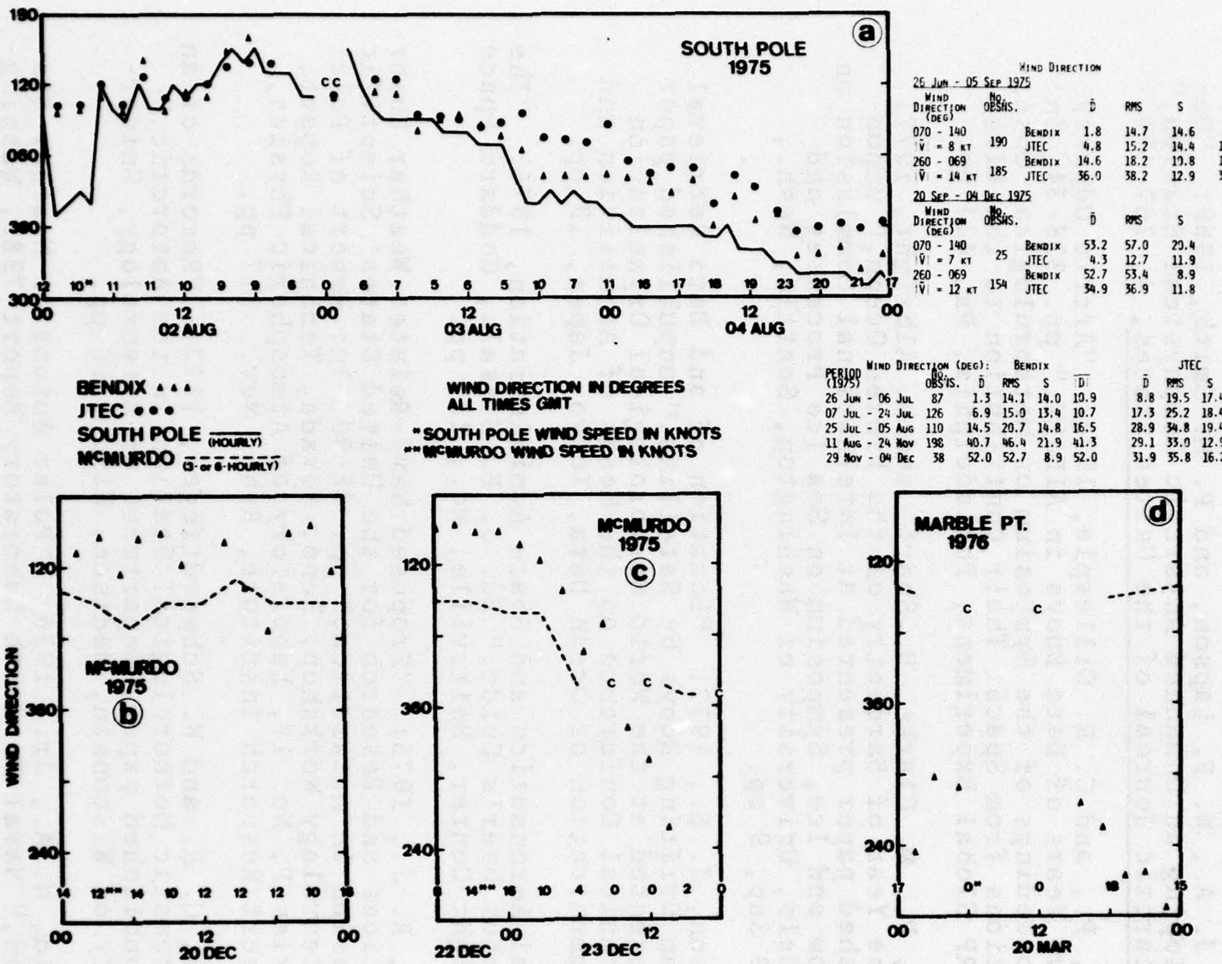
PERIOD (1975)	No. OBSNS.	Hamilton $\bar{D}$	Hamilton RMS	Hamilton S	Hamilton $\overline{\lvert D \rvert}$	Paroscientific $\bar{D}$	Paroscientific RMS	Paroscientific S	Paroscientific $\overline{\lvert D \rvert}$
26 Jun - 06 Jul	22	0.3	0.5	0.4	0.4	-1.1	1.1	0.4	1.1
07 Jul - 24 Jul	32	0.1	0.4	0.4	0.4	-1.0	1.1	0.6	1.0
25 Jul - 05 Aug	28	-0.1	0.4	0.4	0.3	-0.3	0.5	0.4	0.4
11 Aug - 24 Nov	57	-0.1	0.4	0.4	0.3	-0.6	0.8	0.5	0.6
29 Nov - 04 Dec	37	-0.2	0.3	0.2	0.2	-0.1	0.3	0.3	0.2

Figure 6. Pressure



Wind Speed (kt): PERIOD (1975)	Bendix No. OBSNS.	$\bar{D}$	RMS	S	$\overline{\lvert D \rvert}$	Climet No. OBSNS.	$\bar{D}$	RMS	S	$\overline{\lvert D \rvert}$
26 Jun - 06 Jul	89	-2.3	3.1	2.1	2.6					
07 Jul - 24 Jul	167	-2.1	3.2	2.5	2.7	INOPERABLE				
25 Jul - 05 Aug	122	-3.4	4.0	2.1	3.6	122	-3.5	4.0	1.9	3.6
11 Aug - 24 Nov	247	-2.5	3.5	2.5	3.0	247	-2.5	3.4	2.2	2.8
29 Nov - 04 Dec	13	-2.2	2.6	1.3	2.2	38	-1.4	2.0	1.4	1.6

Figure 7. Wind Speed



Wind Direction

26 Jun - 05 Sep 1975

Wind Direction (deg)	No. Obsns.		$\bar{D}$	RMS	S	$\overline{\lvert D \rvert}$
070 - 140	190	Bendix	1.8	14.7	14.6	9.7
$\lvert\bar{V}\rvert$ = 8 kt		JTEC	4.8	15.2	14.4	10.1
260 - 069	185	Bendix	14.6	18.2	10.8	15.4
$\lvert\bar{V}\rvert$ = 14 kt		JTEC	36.0	38.2	12.9	36.0

20 Sep - 04 Dec 1975

Wind Direction (deg)	No. Obsns.		$\bar{D}$	RMS	S	$\overline{\lvert D \rvert}$
070 - 140	25	Bendix	53.2	57.0	20.4	53.2
$\lvert\bar{V}\rvert$ = 7 kt		JTEC	4.3	12.7	11.9	9.7
260 - 069	154	Bendix	52.7	53.4	8.9	52.7
$\lvert\bar{V}\rvert$ = 12 kt		JTEC	34.9	36.9	11.8	35.2

Wind Direction (deg):		Bendix				JTEC			
Period (1975)	No. Obsns.	$\bar{D}$	RMS	S	$\overline{\lvert D \rvert}$	$\bar{D}$	RMS	S	$\overline{\lvert D \rvert}$
26 Jun - 06 Jul	87	1.3	14.1	14.0	10.9	8.8	19.5	17.4	14.1
07 Jul - 24 Jul	126	6.9	15.0	13.4	10.7	17.3	25.2	18.4	19.2
25 Jul - 05 Aug	110	14.5	20.7	14.8	16.5	28.9	34.8	19.4	30.6
11 Aug - 24 Nov	198	40.7	46.4	21.9	41.3	29.1	33.0	12.9	30.4
29 Nov - 04 Dec	38	52.0	52.7	8.9	52.0	31.9	35.8	16.2	33.1

Figure 8. Wind Direction

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